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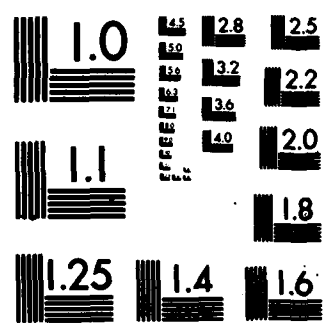

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THE USE OF FLUORESCENT MINI-TUFTS FOR HYDRODYNAMIC FLOW VISUALIZATION

D. R. Stinebring and A. L. Treaster

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A new flow visualization technique was demonstrated in the 12-inch (0.305 m) and 48-inch (1.22 m) diameter water tunnels of the Applied Research Laboratory at The Pennsylvania State University (ARL/PSU). The technique features the application of large numbers of extremely fine nylon mono-filament fiber tufts to a model's surface. The fibers are treated with a fluorescent dye and rendered visible by ultraviolet light.

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Subject: The Use of Fluorescent Mini-Tufts for Hydrodynamic Flow Visualization

Reference: Crowder, J. P., "Fluorescent Mini-Tufts for Non-Intrusive Flow Visualization," McDonnell Douglas Corp. Report MDC J7374, February 1977.

Abstract: A new flow visualization technique was demonstrated in the 12-inch (0.305 m) and 48-inch (1.22 m) diameter water tunnels of the Applied Research Laboratory at The Pennsylvania State University (ARL/PSU). The technique features the application of large numbers of extremely fine nylon mono-filament fiber tufts to a model's surface. The fibers are treated with a fluorescent dye and rendered visible by ultraviolet light.

Acknowledgment: This work was sponsored jointly by Codes NSEA 63R-3 and NSEA 05H of the Naval Sea Systems Command

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INTRODUCTION

The need for improved flow visualization techniques in the Fluids Engineering Department of ARL/PSU has been apparent for some time. The knowledge of surface flow patterns is important to both the designers of hydrodynamic hardware and the test engineers as they correlate and analyze experimental data as a function of differing flow phenomena. Specifically, the identification of regions of separated flow is especially important. Various flow visualization schemes (smoke, yarn tufts, oil-paint mixtures, etc.) have been used with varying degrees of success at ARL/PSU. However, these techniques are generally limited by such factors as low velocities, coarse grid spacings, and difficult interpretation of the resulting flow patterns. Particularly difficult has been the development of flow visualization techniques suitable for water tunnel testing in the velocity range usually employed at ARL/PSU (V_∞ > 20.0 ft/sec). Hydrogen bubble techniques are available but are usually limited to velocities less than 5.0 ft/sec (1.52 m/sec). Thus, the adaptation of a new air tunnel flow visualization technique (Reference 1) discussed at the 1979 Subsonic Aerodynamic Testing Association (SATA) meeting to water tunnel testing at high flow velocities was of definite interest.

This new technique utilizes what are referred to as "fluorescent mini-tufts." The basis of the method is the use of extremely fine nylon mono-filament fibers, which have been treated with a fluorescent dye, for the tufts and a process of attaching the tufts to the model surface with small drops of liquid adhesive. The tufts are rendered visible for viewing or photography by ultraviolet light.

The use of tuft material for flow visualization with visible light is not new except that the tufts had to be made quite large to be visible against a reflective background. In many instances these large tufts could significantly alter the flow pattern.

The important feature of this new technique is that under strong ultraviolet illumination, which is invisible to the unaided eye, the fluorescent tufts stand out in sharp contrast with the nonfluorescent surface to which they were applied. Thus, very small tufts which will not disturb the flow pattern can be applied to the model and still be visible. For the tufts to be photographed, a filter must be used over the camera lens to remove the reflected ultraviolet illumination. The filter, termed a barrier filter, is necessary because most photographic emulsions are sensitive in the ultraviolet wavelengths. If the reflected ultraviolet reflection were not removed, glare from the surface would obscure the view of the mini-tufts.

FLUORESCENT MINI-TUFTS IN AIR TUNNEL TESTING

The technique for air tunnel flow visualization was developed by J. P. Crowder, formerly of the McDonnell Douglas Corporation, and is detailed in Reference 1. Highlights from this reference are itemized below:

1. The tufts are 0.0007 to 0.0017-inch (0.018 to 0.043 mm) diameter mono-filament attached with a nitrocellulose cement usually in 0.5-inch (12.7 mm) grids.

2. The fluorescent dying process, model preparation, and tuft attachment are discussed.

3. Basic light source and light filtering requirements as well as photographic guidelines are presented.

4. The advantages of the technique are:

   a. Very large numbers of tufts can be applied which have survived many hours of high Reynolds number air tunnel testing.

   b. The tufts are so small that they do not appreciably alter the flow field and, therefore, define local flow direction and regions of separated flow.

   c. Comparisons between tufts-on and tufts-off runs over a Mach number range from 0.5 to 2.4 have indicated negligible interference effects on lift and drag measurements.

FLUORESCENT MINI-TUFTS IN WATER TUNNEL TESTING

To the authors' knowledge, fluorescent mini-tufts have not been used in water tunnel testing. To this end a developmental program was initiated at ARL/PSU. At the present time the following goals have been achieved.

1. A nylon mono-filament fiber of approximately 0.0013-inch (0.03 mm) diameter have been procured which will withstand the rigors of water tunnel testing.

2. A process for treating the mono-filament with a fluorescent dye which would be insoluble in water was demonstrated.

3. Several adhesive and attachment procedures were tried before one that produced a small waterproof glue area strong enough to withstand the hydrodynamic forces on the tufts was found.

On January 18, 1980 the first phase of the water tunnel application of the fluorescent mini-tufts was demonstrated in the ARL/PSU 12-inch (0.305 m) diameter water tunnel. A 6.0-inch (0.152 m) long, 3.0-inch (0.076 m) diameter strut of semicircular cross section was installed in the test section. This particular model was selected because of the strong separated region downstream of the maximum thickness point. Approximately 100, 0.5-inch (12.7 mm) long fluorescent mini-tufts were attached in a 0.5-inch (12.7 mm) square grid to the curved surface of the strut (see Figure 1). The method for application of the tufts was as follows:

1. The surface was first cleaned with solvent, being careful to remove all traces of dirt and oil.

2. A strand of tuft material approximately five inches long was aligned with the mean flow direction and secured to the strut with a piece of masking tape at each end.

3. Small droplets of cyanoacrylate adhesive were then applied, with a slightly blunted straight pin, at approximately 0.5-inch (12.7 mm) intervals along each strand. Droplets of a size smaller than 0.025-inch (0.635 mm) diameter were obtained using this method. The adhesive was typically 0.002-inches (0.051 mm) thick (including the tuft) for a 0.023-inch (0.584 mm) diameter spot. [It is not known at this time what is the minimum amount of adhesive required to secure the tufts to a body.]

4. When the adhesive had dried, the tufts were cut at the aft end, just forward of the next drop of adhesive. The strands were cut using a small sharp blade (such as an Exacto knife blade) that was heated and quickly applied to the tuft. An improved method for cutting the tufts has recently been utilized. A length of small gauge wire is wrapped around the tip of a soldering iron with one end of the wire projecting approximately 0.25-inch (6.35 mm) out from the tip. The voltage to the soldering iron is raised to a point where the tuft material just parts when touched by the end of the wire. A heated tool for cutting the tufts does not mar the model surface since no pressure is used in parting the strands.

Under incandescent light the tufts were barely visible to the unaided eye. But when the test section was draped with a black cloth and the strut illuminated with a long wave ultraviolet light source, the tufts were brightly fluorescent against the dark background. The light source for these observations were two parallel 40 watt, long-wave ultraviolet light tubes (black lights). Due to the intense fluorescence under ultraviolet light, the tufts appear significantly larger in diameter than their true physical size. (This phenomenon can also be recorded photographically according to Reference 1.) As the test section velocity was increased from 5.0 to 35.0 ft/sec (1.5 to 8.9 m/sec), the region of separated flow, as indicated by the mini-tufts, was clearly observed to move downstream from the 90° position (see Figure 1) as the Reynolds number was increased.

The mini-tufts were underwater for 54 hours and exposed to a maximum test section velocity of 35.0 ft/sec for one and one-half hours, with no tufts lost or broken.

The first water tunnel test was conducted on a stationary model with a continuous light source, but the use of fluorescent mini-tufts would be most useful if it could be applied to observing the flow pattern on propeller blading. For application of the technique in a rotating system, stroboscopic ultraviolet illumination is required. Certain xenon flash lamps have significant output in the ultraviolet region of the spectrum, and these lamps can be used by filtering out the visible light. An exciter

filter removes the visible light while passing a significant portion of the ultraviolet. Exciter filters manufactured by Corning Glass Works have been used with a number of stroboscopic light sources at the Garfield Thomas Water Tunnel (GTWT) at ARL/PSU. It was discovered that only the Chadwick-Helmuth point sources exhibit significant ultraviolet output. This source together with the exciter filter was used to view the strut installed in the 12-inch (0.305 m) diameter water tunnel. There was significant illumination for viewing the tuft pattern.

In the next phase of testing a 6.75-inch diameter propeller was installed in the 12-inch water tunnel and two blades were instrumented with tufts 0.5 to 0.1-inch long. Tufts were attached to the pressure surface of one blade and to the suction surface of the other. When viewed with the filtered stroboscopic lighting under test conditions the tufts were rendered visible. The propeller was tested at both on and off design conditions. At the design condition, separated regions and regions of secondary flows near the root were visible. In some cases though, there was only a slight movement at the aft section of the tuft. It was not known if the flow was unstable or whether the movement could be a function of the tuft length. Further work is needed in the interpretation of the tuft patterns.

An array of tufts was next applied to the afterbody of a model in the 48-inch water tunnel. It was not known if sufficient ultraviolet output was available to illuminate the tufts through approximately two feet of water and the tunnel windows. In addition, for this particular model a tunnel liner was installed, with the section over the viewing window made of Lexan®. Lexan absorbs a high percentage of energy in the ultraviolet wavelengths so it was not known if the tufts could be observed. Tufts 0.5-inch long were applied on an area of approximately 5-inches by 11-inches with the larger dimension in the direction of the flow. The area about the tunnel test section was draped with black cloth and made light free. Two strobes with attached exciter filters were operated from an oscillator at close to the maximum allowable frequency. This provided the highest ultraviolet output. The tuft array was visible with this arrangement although the brightness was far below that observed in the 12-inch water tunnel tests. However, the required information regarding the flow field over the afterbody was obtained as a result of the technique.

Further work is underway to increase the intensity of the fluorescent mini-tufts. This work includes the following areas:

1. The construction of quartz inserts into the tunnel windows for minimum ultraviolet absorption.

2. Construction of the tunnel liner sections over the inner surface of the windows of materials that transmit a greater amount of ultraviolet light.

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3. The obtaining of information regarding stroboscopic light sources that are rich in ultraviolet output.

Continuing effort is being placed on the development of photographic techniques relative to the in-water application of the fluorescent mini-tufts.

SUMMARY

The use of fluorescent mini-tufts enables the visualization of both air and water tunnel surface flow patterns. Due to the small tuft size, they can be usable on model scale propulsor blading. This application would not necessitate the start-up and shut-down procedure currently required by the oil-paint film technique. The use of the fluorescent mini-tufts may also be possible on full-scale submarines or surface ships. This application would require night time viewing/photography to eliminate the visible light and the use of high intensity ultraviolet light sources and special observation arrangements.

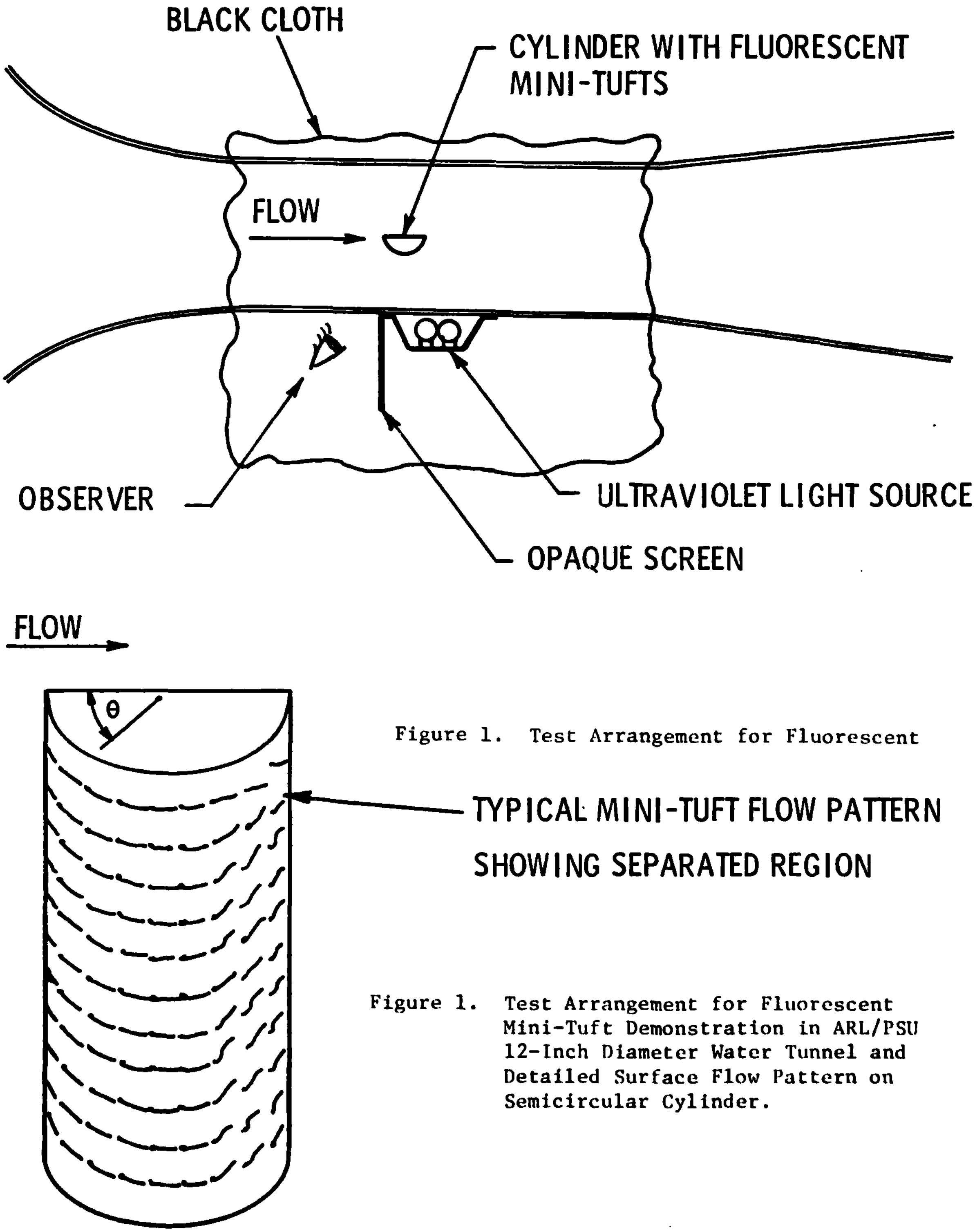

Figure 1. Test Arrangement for Fluorescent

Figure 1. Test Arrangement for Fluorescent Mini-Tuft Demonstration in ARL/PSU 12-Inch Diameter Water Tunnel and Detailed Surface Flow Pattern on Semicircular Cylinder.

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